XR ASSOCIATION DEVELOPERS GUIDE:
AN INDUSTRY-WIDE COLLABORATION FOR BETTER XR

CHAPTER 5: DESIGNING IMMERSIVE SOLUTIONS FOR HEALTHCARE

XR ASSOCIATION

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DESIGNING IMMERSIVE LEARNING FOR HEALTHCARE

This new chapter of the Developers Guide continues to focus on those developing platforms and applications for XR through establishment of an evolving set of best practices – this time with an emphasis on the importance and necessity of creating programs that are tailored for the healthcare industry.

XR hardware is evolving rapidly, and while there are facets of XR hardware that are unique to each manufacturer, all are working to transform the way that people receive healthcare and reduce the barriers for improving healthcare in conjunction with software development partners. As software developers look to develop applications for use in the XR enterprise space, this guide is intended as a baseline of best practices for bringing XR to healthcare.

This guide is not meant as an exhaustive source on designing for XR for healthcare, and we recognize that these best practices must continually evolve. This will require ongoing input from relevant stakeholders, including standards setting bodies who are also working to establish industry standards in healthcare.

Additionally, many countries around the world have established laws governing software for healthcare, and we urge software developers to follow all healthcare related laws and regulations in their applicable jurisdictions as they create innovative designs and solutions using XR.

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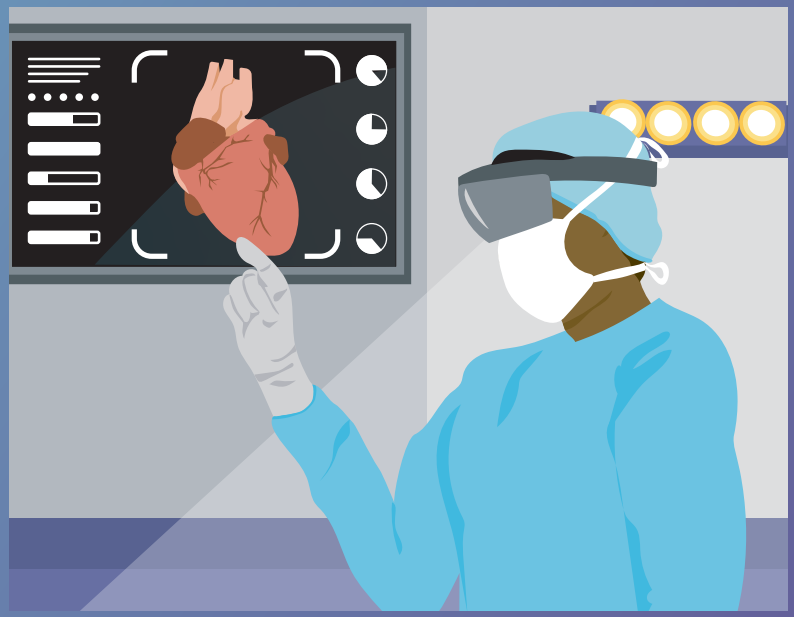


XR technologies have already demonstrated significant benefits to the healthcare field and are improving patient outcomes.[1] Examples of current uses of medical XR technologies in medical settings include for post-traumatic stress disorder, dementia or Alzheimer's, pain management, physical therapy, patient education, mental health care, and stroke recovery, to name a few.

Medical XR is likely to be an integral part of the future of healthcare, and it holds tremendous promise for healthcare, whether used as a training tool for doctors and nurses, as a diagnostic tool, as a therapy for a variety of conditions, or for other uses. In a survey of health care clinicians, conducted by XRA, 83% of clinicians recognize that XR is already or likely will impact healthcare. Three out of four respondents anticipate the technology affecting them professionally.

This Developers Guide is intended to provide insights and considerations for those who are seeking to build XR experiences for the medical field. This guide moves from general business guidance to technical affordances of XR, and considerations of technology innovation. At the end of this guide are six healthcare use cases and some unique considerations for developers who are seeking to design experiences in those areas.

GENERAL CONSIDERATIONS FOR XR HEALTHCARE SOFTWARE

MARKET AND AREA OF EXPERTISE

As with all healthcare technology, advancing XR in healthcare presents challenges given the complexity of medical science, the bureaucratic nature of the healthcare system from hospitals to insurers and everyone in between, complicated procurement structures among healthcare companies, and the strict government regulation of the healthcare field, including software intended for medical uses.

Because healthcare is such a complicated system, it's important for software developers to understand who their audience is and to be clear about what intended use they are hoping to address with the technology.

Medical professionals use evidence-based research studies to guide much of their patient care as well as how they educate new doctors, nurses, and other medical personnel. Any medical XR application should be informed by the latest science.

It is imperative that software developers consult with their target medical professional audience and use up-to-date research studies on their areas of interest to inform the content of their medical XR program, its functionality, and its treatment or educational goals, among other things. Well-established sites, such as ResearchGate and Google Scholar, offer data on evidence-based research studies on a wide variety of medical topics, including effective treatments using medical XR.

GENERAL CONSIDERATIONS FOR XR HEALTHCARE SOFTWARE

3D MODELS

Creating and using 3D models (i.e. virtual humans, object libraries, digital twins) in healthcare generally requires the use of several technologies: Internet-connected devices; XR technology; cloud computing; and artificial intelligence (AI). These technologies work in tandem to create the model, capture the inputs, store the inputs, and analyze the resulting data.

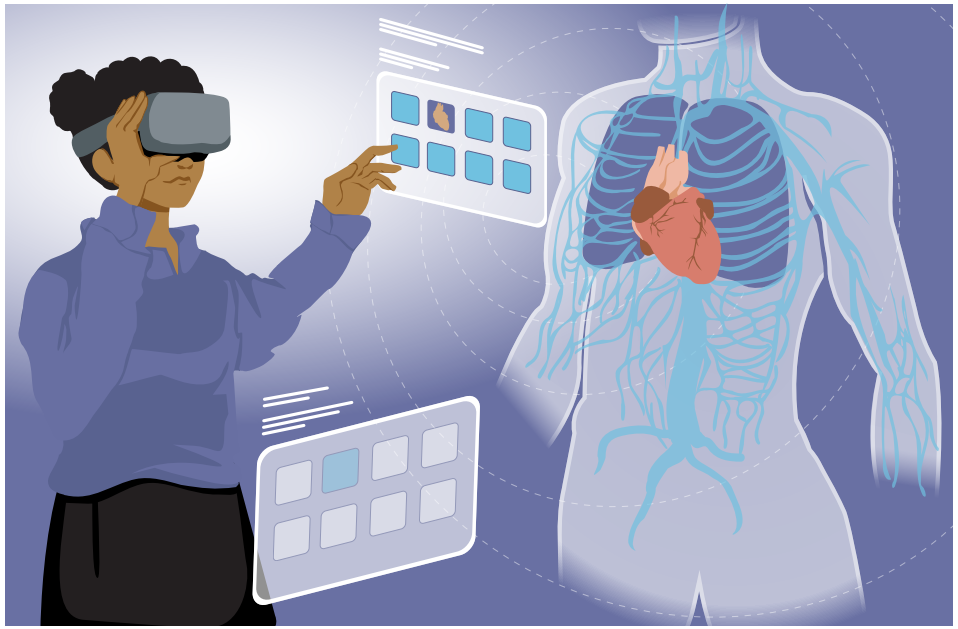
3D models are used in other industries, such as for aircraft and spacecraft manufacturing. 3D models in the healthcare space are primarily used for medical education, patient-specific surgical simulation or practice, and research.[2]

For medical education, 3D models can be used to illustrate real-life patients and the outcomes from medical interventions, surgical or otherwise.[3] For surgical procedure planning and/or pre-operative rehearsal, healthcare professionals can practice a complicated surgery on a 3D model of the actual patient to gauge potential risks and complications that could arise from surgical intervention.[4]

For research, some projects are using 3D mapping of organs to better understand diseases and disorders. For example, the Living Brain project[5] is using crowdsourced 3D brain mapping of patient brains from around the world to better understand epilepsy and improve surgical interventions for epileptic patients.

DEVELOPMENT PLATFORM AND SOFTWARE DEVELOPMENT KIT DESIGN OPTIONS

When choosing a development platform, such as Unreal Engine or Unity, and/or a software development kit with which to build an XR application for a healthcare setting, the



following considerations should be taken into account, depending on the developer's needs:

- Rendering quality
- Interactive responsiveness
- Hardware compatibility
- Cross-platform capabilities

When considering hardware compatibility, developers should consider whether the hardware that is likely to be used for the application has the appropriate level of graphics processing ability for the app. Hardware and SDK or API capabilities should also be considered when designing apps that require haptic feedback, gaze tracking, limb tracking, and other features that may enhance a user's feeling of embodiment while using an app.[6]

Another important consideration is whether the software developed using a development platform or software kit can be used across platforms and is otherwise compatible with other types of medical technology that will need to be in use simultaneously.

HARDWARE MANAGEMENT AND INFRASTRUCTURE REQUIREMENTS

Effective XR hardware management is essential for the successful deployment of XR technology in healthcare, ensuring efficient operations, safety, and scalability. The healthcare environment demands careful consideration of various aspects of XR hardware management, including charging and power, storage, mobility, software management, and hygiene. Software

PERSONAL MEDICAL DEVICE SAFETY

XR applications may need to interact with other medical technologies and software programs to ensure seamless care for patients.

Importantly, developers might want to consider whether their preferred XR headset is compatible with personal medical devices (ex. pacemakers) and other hospital or healthcare facility equipment and technology.

VR and AR headsets may contain magnets or other components that emit radio waves that could interfere with other electronics that are being used in close proximity to the headsets. This includes pacemakers, hearing aids and defibrillators. Because of the potential for an adverse medical event, most XR hardware manufacturers recommend that those who have pacemakers or other implanted medical devices refrain from using their equipment without first verifying with the medical device manufacturer that a particular XR headset will not interfere with their implanted device.

Additionally, headsets may not be advisable for those with epilepsy, traumatic brain injury, or other cognitive/sensory impairment.

Some headset manufacturers also warn that users should consult with a doctor before using any XR headset if they are pregnant, have preexisting binocular vision abnormalities or psychiatric disorders, or suffer from a heart condition or other serious medical condition.

While software designers are not responsible for hardware development, they may find it prudent to include warnings in their products about the potential for interference with other medical devices or medical conditions.

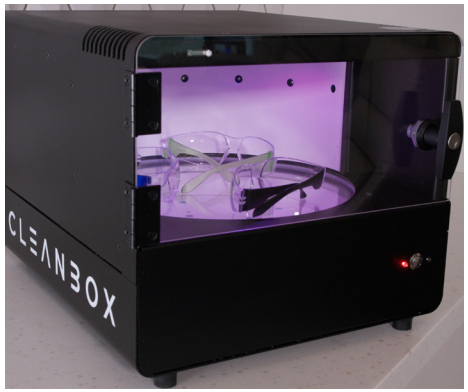


Photo credit: Cleanbox Technology

Photo credit: Uvisan

developers should consider hardware management needs when designing for XR.

XR HARDWARE CHARGING AND POWER

Reliable access to power sources is crucial for both charging standalone XR headsets and operating tethered XR devices in healthcare settings. There are diverse charging solutions suitable for healthcare environments, including charging carts, stations, and wireless charging options. It is also important to follow charging best practices and recommendations for healthcare XR devices.

XR HARDWARE STORAGE AND MOBILITY

Properly securing and making XR headsets available when needed requires tailored storage and mobility solutions for XR devices in healthcare. Mobile cabinets with charging capabilities and medical-grade trolleys with battery packs are suitable for standalone and tethered XR headsets. In dedicated XR labs, wall-mounted racks may be appropriate, and in environments with tethered XR headsets, combining storage and hygiene in a single unit is feasible.

Mobility is especially crucial in point-of-care situations, where XR headsets are brought directly to patients. Additionally, secure, portable storage cases facilitate moving XR headsets over longer distances or between locations.

XR HARDWARE HYGIENE

Maintaining hygiene in XR healthcare environments is paramount. XR headsets are unique because they are applied directly to a user's head and face, making them more vulnerable to infection transmission. While antibacterial wipes have been the primary cleaning method, they have limitations, such as waste production, user training requirements, and potential damage to headsets.

UVC LED technology[7] has been offering a faster, safer, and more environmentally friendly decontamination solution. It achieves high decontamination rates in a very rapid time, without damaging headsets, lenses, or electronics.

Certain healthcare settings, such as surgical sites, may require a validated, standard operating procedure that has been approved by appropriate standards and regulators. This will likely include a Caviwipe, UVC box, hand hygiene process, sterile bag for storage, and possibly other predetermined protocols.

It's important to understand that existing protocols tend to be siloed by the healthcare segment, healthcare institution, and/or individual hospital. Developers should seek to determine which protocols and standards may apply to their applications. In the future, more uniform standards may be agreed upon for specific use cases which will drive efficiency in providing a single solution to multiple providers.

In settings where healthcare-associated infections (HAIs) are a concern, effective hygiene standards are essential not only for safety but also for user perception. Promoting high hygiene protocols, especially with UVC LED technology, can make users feel safer, enhance inclusivity, and drive XR adoption.

Implementing and communicating the highest level of XR hardware hygiene to users of the XR application enhances safety, inclusivity, and adoption of XR technology in healthcare, ultimately impacting ROI and future growth.

GENERAL CONSIDERATIONS FOR XR HEALTHCARE SOFTWARE

XR MANAGEMENT WORKFLOWS AND PROTOCOLS

Appropriate XR hardware workflows and protocols are necessary to prevent costly mistakes, ensure efficiency, and meet regulatory standards. Protocols and workflows should be tailored to the type of XR hardware and the specific constraints of the healthcare deployment.[8]

ASSESSMENT TOOLS

A major benefit of using digital technology in medical treatment is the potential ability to gather data on the effectiveness of such treatments. Given that XR healthcare technologies are still emerging, proof of concept will be important to engendering trust in XR-based treatments and therapies. Therefore, developers should include mechanisms to collect data on the effectiveness of their XR tools and/or data on the progress patients may be making while using XR healthcare tools.

Assessment tools can assist medical professionals in both assessing the progress of an individual patient as well as gauging the success of the treatment or therapy overall on a larger patient group. The latter could be used to produce scientific papers or studies of particular XR-based medical interventions.

Such data collection should adhere to relevant medical privacy rules and laws, and in general, data collected on groups of patients should be anonymized.

GOVERNMENT REGULATION

The healthcare industry, in general, and healthcare products, specifically, are heavily regulated in many countries around the world. For example, in the United States, the U.S. Food and Drug Administration ("FDA") enforces strict regulatory requirements relating to medical devices, including what constitutes a medical device.[9]

The FDA specifically is charged with responsibility for ensuring the safety and efficacy of products and services within its domain. This includes requirements pertaining to documentation of product requirements and design, development controls, testing, quality assurance, and even marketing and advertising. If you are a developer, tester, manufacturer, distributor, or any other contributor to the medical device ecosystem, it's likely that FDA requirements will play an important role, not only in the production of the particular medical device or software for which you are responsible, but to your operations in general.

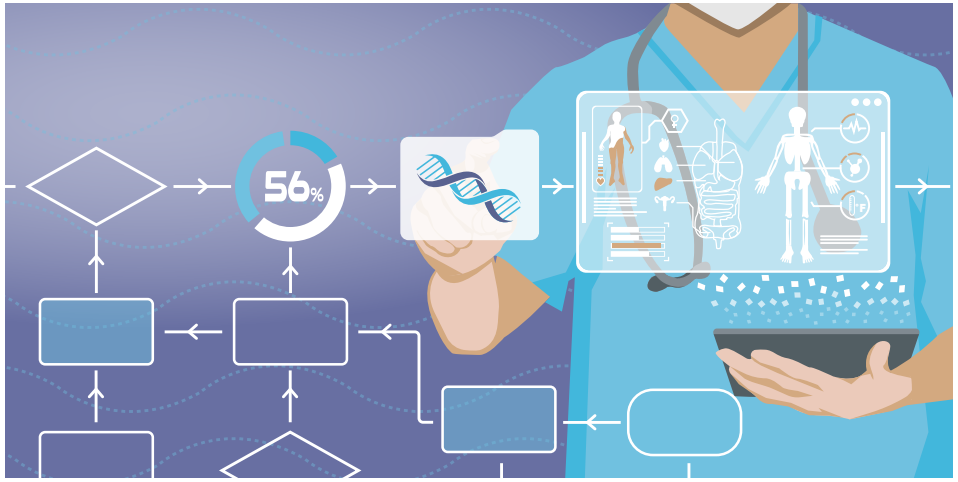
FDA has already approved several devices that employ AR or VR as medical devices.[10] Of course, some devices intended for wellness or healthcare may not need FDA approval, so developers should consult legal experts on whether their applications meet legal definitions of medical devices to ensure compliance with current law. Some guidance on the FDA process can be found in the agency's General Principles of Software Validation; Final Guidance for Industry and FDA Staff.[11]

Other health technology regulations in the U.S. include Federal Trade Commission regulations on health claim marketing[12] and Department of Health and Human Services regulations on patient data privacy under the Health Insurance Portability and Accountability Act (HIPAA).[13]

Some U.S. states also have laws related to medical devices, patient privacy, and health claim marketing, among other things.

Increasingly, state privacy laws, such as the California Consumer Privacy Rights Act[14], recognize a special category of personal information, sometimes called "Sensitive Information," calling for heightened privacy, security, and disclosure requirements. Much of the health-related data discussed in this chapter potentially falls into this category.

Some countries have enacted accessibility laws to support full participation of patients with disabilities. Developers should familiarize themselves with the accessibility laws of the countries where their XR tools



GENERAL CONSIDERATIONS FOR XR HEALTHCARE SOFTWARE

are intended to be used. Some examples of these laws are the European Accessibility Act[15] and the U.S. Americans with Disabilities Act.[16] Among other things, these types of laws stipulate the rights to health, education, and effective communication for individuals with disabilities. They also provide examples of settings where these laws apply.

We urge software developers to follow all laws and regulations in their applicable jurisdictions[17] as they create innovative designs for XR in healthcare.

IN-PATIENT OR OUT-PATIENT USE

If developing therapies for specific medical conditions, developers may want to consider whether their app is intended to be used under the supervision of a medical professional or by the patient alone or at home.

- Such considerations can help guide the general accessibility of the XR applications as well as how much training or education may be needed to operate the hardware and the user interface.
- For example, training and educational materials for medical XR intended for use by a patient alone at home will need to refrain from using medical jargon or terms that most patients are unlikely to understand, and the program may need multi-modal operational controls to ensure maximum accessibility.

XR PROGRAM TOOLS

GESTURE AND GAZE TRACKING

In the healthcare setting, XR often needs physical inputs to operate. These physical inputs can provide important data points, are useful for traditional diagnosis and treatment purposes, and are critical for shaping robust immersive experiences for patients in real time.

For many healthcare applications, gesture and gaze tracking will be important for understanding what is happening with the patient. For example, if a patient is otherwise unable to move, gaze tracking could assist the patient in communicating with medical staff. A patient's gestures or movements while using XR equipment may help medical professionals pinpoint the location of injuries or other conditions that affect motor skills.

Developers should consider whether their application will rely on gesture or gaze-tracking and what degree of precision is necessary. The capabilities of available hardware must match those required by the application and vice versa.

XR PROGRAM TOOLS

IMPORTANCE OF CREATING 'EMBODIMENT'

One of XR's most compelling benefits is its ability to offer users safe, virtual experiences that closely simulate real-world experiences. Where appropriate, software developers should consider how to optimize users' sense of embodiment in XR medical applications. Generally, the more complete the sensory input, the better the resulting sense of embodiment will be.

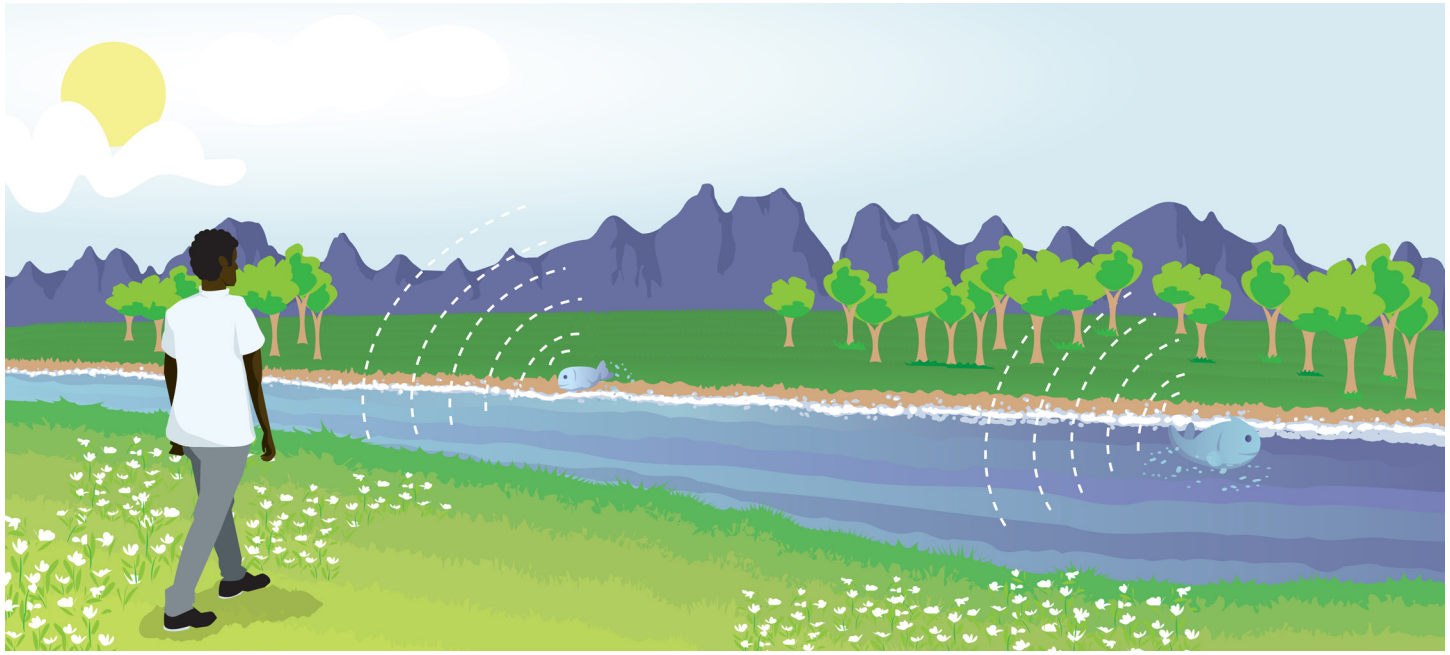
Using gesture and gaze input data as well as haptic feedback output, researchers have found that users feel more embodied in immersive environments when the app follows their gaze and simulates the physical sensations of touching and/or holding something.

Depending on the type of medical XR system being developed, the user's perception that their movements and actions are a natural extension of themselves could be key to the efficacy of the app. For example, if the XR environment shows a patient how to use a new prosthetic limb, the experience should closely mimic the look and feel of a real prosthetic limb. Similarly, medical professionals learning to give vaccinations and other types of subcutaneous injections might need to "feel" the weight of the syringe and the resistance of the arm tissue and muscle.

Of course, some types of input data and feedback mechanisms call for specialized hardware components that may be costly or in short supply. Additionally, some data may require special permissions to be granted on a user-by-user basis. Developers should keep in mind that different implementations of their applications may need to make different input and output mechanisms available. Therefore, developers should carefully consider what sensory input and feedback is most impactful for a given application.

USE OF SOUND

Simulation of sound in XR environments could include spoken dialog, narration, or instruction, and/or music, and/or sound effects, and developers often leverage the power of quality audio to enhance the sense of presence and immersion in virtual environments. Depending on the purpose of the XR system, developers should consider what ambient sounds they have in the environment and how they might enhance the experience or distract from the therapeutic purpose.



GENERATIVE AI

Looking at the future, Generative AI technology will make a significant impact on the XR world. XR developers worldwide have begun to consider how AI will enhance their creative and technological journeys. XR for healthcare will need to work with generative AI to achieve desired results for both healthcare professionals and patients. Already AI is being used in conjunction with XR to analyze patient data, to identify patterns in patient data, to flag abnormalities in medical imaging, and to train medical staff for surgeries, among other things.[18] According to a 2021 study, "the primary motivation for developing the AI-XR applications include 1) training AI, 2) conferring intelligence on XR, and 3) interpreting XR- generated data."[19]

Using machine learning, generative AI may be employed in XR to:

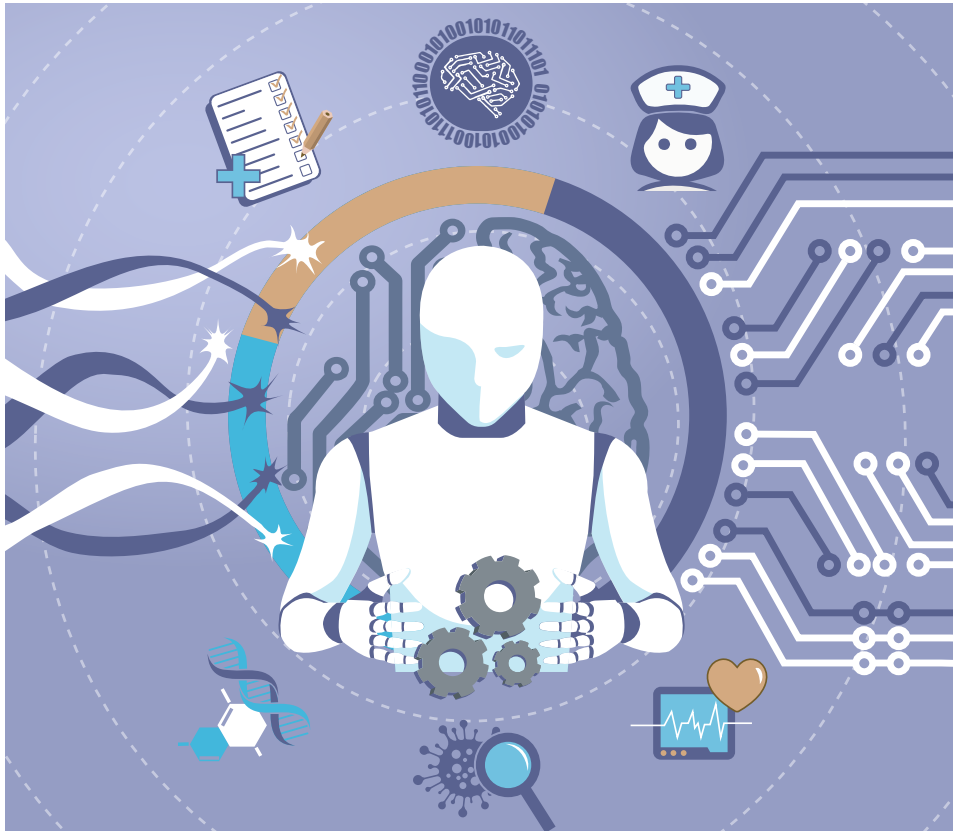
- Inform individual patient treatment programs.
- Analyze pharmaceutical clinical trial data to identify what compounds may be most effective in what treatment areas
- Help screen and diagnosis for chronic diseases
- Create realistic training simulations that can adapt to the student's unique learning approach and that can deploy lifelike virtual characters

GENERATIVE AI

Machine learning technology and large language models can augment XR for medical education, for example, by creating realistic but random simulations. A July 2022 Future of Healthcare Journal article posited that AI could be used to "create virtual instructors, with AI-generated characters. This could be used to create 'fake' virtual patients with synthetic clinical presentations in the future."[20] The same paper proposed that AI could help to anonymize patient data gathered by XR and other technologies to both protect patient privacy and give researchers data with which to explore new therapies and medical insights into patient care.

In anonymizing data, generative AI could also create "synthetic" datasets to improve research and address algorithmic bias. It could also be used to audit other clinical applications of machine learning. The Future of Healthcare Journal article notes, "Where datasets are imbalanced and not representative of the population they aim to serve, generative AI in the form of synthetic minority oversampling technique (SMOTE) may be used to selectively augment the representation of minority data points. In this way, there is potential for synthetic data to help mitigate algorithmic bias in healthcare uses of machine learning, both in constructing algorithms and responding to dataset shift. Synthetic data may also be used to audit medical applications of machine learning by exposing algorithms to novel simulated data in adversarial testing."

XR developers can harness generative AI to increase the realism of immersive environments and the "intelligence" and responsiveness of virtual characters, such as a virtual clinician or a virtual patient that can display human-like behaviors, from facial and verbal reactions to bodily movements and functions in response to human input.



ACCESSIBILITY AND DIVERSITY

Accessibility for a spectrum of potential disabilities and conditions – both temporary and permanent – should be built into any XR application. That includes accessibility for the blind and visually impaired, the deaf and hard of hearing, those with mobility disabilities, and those who are neurodivergent or have cognitive disabilities. See XRA's DEVELOPERS GUIDE, CHAPTER THREE: Accessibility & Inclusive Design in Immersive Experiences[21] for specific ways to build inclusive and accessible XR environments. Of course, there are also a number of accessibility considerations developers should take into account for healthcare applications.

- **Content Diversity:** Developers also should take care in the development of the content of their apps, particularly if the content includes gamification or storylines.
    - — Content should be relevant or appealing to a diverse set of users and should steer clear of topics, images, or other content that could be misinterpreted, misunderstood, or considered offensive by those from diverse backgrounds.[22]
    - — Likewise, if human avatars are used, they should include options for individuals from different backgrounds, genders, abilities, and skin colors.
    - — If there are character interactions in the experience, developers may consider having non-user characters use different dialects when speaking. Choices such as this may serve as subtle messages to users that all are represented.

ACCESSIBILITY AND DIVERSITY

- **Simple Controls:** Developers should consider making the controls for medical XR simple. Because many users – both patients and medical professionals – may be unfamiliar with the technology (nor familiar with similar gaming or entertainment technologies), simple controls should be used, and if using a button-type controller, users should not be required to use more than one or two buttons to navigate the XR environment.

- **Language Needs:** The languages and cultures of the majority of the intended users should be assessed from the onset of the development if the XR application is intended to be used by patients. An effort should be made to have the tool available in those languages and to create a mechanism to grow the number of languages in the future.

- **Input from the Disability Community:** Advice on best practices in universal design from consultants with disabilities and from individuals from diverse backgrounds must be sought. As users of accessibility features, they can provide critical first-hand input during the early stages of the development.

XR IN HEALTHCARE USE CASES

MENTAL HEALTH

Use cases for mental health and wellness run the gamut from traditional clinical applications, such as cognitive behavioral therapies and group therapy, to general wellness uses, such as meditation and relaxation.

Developers should keep in mind that clinical use cases receive more regulatory scrutiny than general wellness applications and should consult relevant regulatory experts for guidance.

CREATING A CALM AND STRESS-FREE ENVIRONMENT

XR-based treatments used in the delivery of mental healthcare may depend on a calming and positive atmosphere to be effective. For example, an environment designed to facilitate group therapy should help encourage sharing and help promote the goals of the therapy group.

A 2021 study[23] of VR use for group therapy noted that patients appreciated environments that they otherwise might not be able to visit, such as sitting under the Northern Lights.

XR IN HEALTHCARE USE CASES

Therapists in the study emphasized the need for the virtual environment to be therapeutically valuable as well as have the capability for therapists to use the environments to guide patients to specific spots as part of the therapeutic intervention.

Importantly, the study noted, "Despite finding most virtual locations calming and relaxing, a few participants acknowledged that specific virtual environments (e.g., shipwreck) might not be appropriate or therapeutic. Furthermore, other virtual environments that seem therapeutic (e.g., a beach) might unknowingly trigger an upsetting memory for some patients (e.g., if a patient has had a bad experience visiting the ocean). It was implied that therapists should start the therapy in a neutral virtual environment (e.g. boardroom) and then through discussion and negotiation allow the group to select locations they find appropriate."

Therefore, developers designing for mental health should consider creating multiple environments for therapists and users to choose, so they might avoid any environments that might trigger negative feelings or be otherwise counterproductive to therapy.

Developers also should strive to use calming colors and sounds, while also allowing users to change the color palette, background features, or ambient sounds to fit their needs and what best creates a calming and/or positive environment for them.

USER PROGRESS

To avoid creating anxiety within a mental health or wellness app, developers might consider showing user progress in ways that do not encourage the competitiveness that gamification of apps sometimes does. Instead, developers might opt to use alternative means of showing a user's progress through the program. For example, user progression should be displayed through means that are individualized and not compared to other players.

DIAGNOSTIC TOOLS

XR shows great promise as a diagnostic aid in medical settings. For example, XR features such as gaze and gesture tracking are being used to diagnose eye and vision issues as well as the progression or improvement in impaired mobility or conditions such as Parkinson's disease. For cognitive conditions, XR applications have been found to be a potentially useful assessment tool to gauge the impact of a brain injury or Alzheimer's or cognitive impairment.

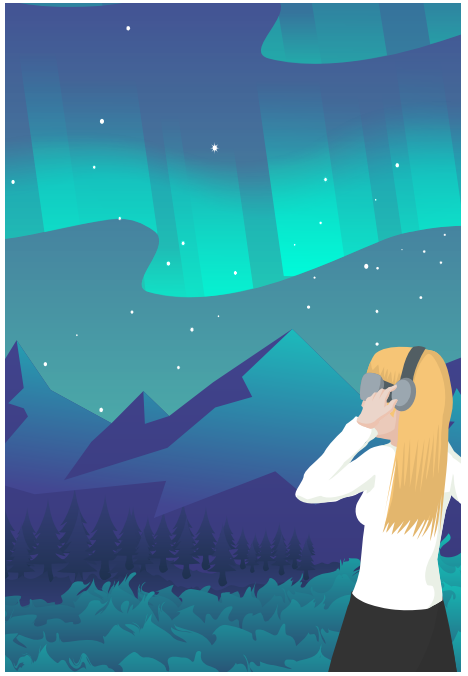
Considerations for developing XR as a diagnostic tool:

- The mechanism of diagnosis should be relevant to symptoms.
- How specialized is the XR diagnosis tool? Does it diagnose multiple diseases or disorders or is it specialized for specific disorders?
- May require review by regulatory authorities, consult with regulatory experts early in development.

SOCIAL VS INDIVIDUAL PATHS

Developers should consider how XR system users will interact, if at all, with clinicians and/or other people during its application.

If a mental health space is intended to be for multiple users to interact and progress together, developers and their consulting clinical specialists should also consider creating a method of ensuring that individual users can adequately participate. For example, in a group therapy setting, developers might offer users a digital "talking stick" or other virtual implement to pass around to encourage participation and prompt others to give their attention to an individual user who is speaking or acting out a task.



XR IN HEALTHCARE USE CASES

"DISTRACTION THERAPY" FOR PAIN, ANXIETY, OR ADDICTION MANAGEMENT

Using immersive experiences for "Distraction Therapy," has been shown to reduce pain and anxiety and help with addiction management issues.[24] Such therapies have been used to help patients and caregivers reduce anxiety about upcoming surgeries and help young children remain calm and stay still for therapies for cancer and other illnesses as well as for medical imaging such as MRIs.

The FDA has already approved at least one application for prescription use to help adult sufferers of back pain.[25] In clinical trials, nearly 65 percent of patients reported a clinically meaningful reduction in their back pain intensity.[26]

Similarly, studies have shown that burn patients have experienced pain relief after using VR distraction therapies. In particular, a 2021 study found that having burn patients engage in immersive experiences that are a facsimile of a cool or cold environment can have positive psychological effects on the perception of pain associated with burns.[27]

In developing XR for distraction therapies, software developers should consider whether the experience should or needs to be completely immersive through a VR headset or whether it should be an AR- or MR-based semi-immersive experience. The types of injuries or conditions to address will likely drive those decisions.[28]

LEARNING AND DEVELOPMENT

General considerations

When creating medical XR for learning and development, software developers should consider whether the learning objectives are better served from a fully immersive, VR environment or whether the information would be better conveyed with an AR or MR overlay onto a real-life surface or medical manikin.

When considering VR, developers should look for platforms and point solutions used in healthcare. No-code platforms, for example, allow instructors, trainers, and/or administrators to own the IP and control their content; with a no-code platform, the process for creation doesn't require engineering or software development by the instructor, trainer, or administrator. It also enables instructors, trainers, and/or administrators to quickly create and test concepts.

Software developers should also include editing and built-in analytic tools that allow instructors, trainers, and/or administrators to:

- Create immersive training courses
- Distribute courses on all platforms and devices
- Analyze user performance data
- Share content within and outside the platform using web and mobile standards.

Software development teams need to collaborate closely with instructors, trainers, clinician subject matter experts, trainees, and/or administrators on the design of educational programs. Instructors and trainers, for example, will need to facilitate the collaboration of different roles and plan for whether the immersive learning experience should be done on an individual basis or as a team. Medical clinicians often operate as a team, so in certain instances, they will need to be able to practice as a team.

When developing training or educational experiences, software developers should consider whether it will be offered in a classroom environment, at a hospital or other clinical space, or remotely from a home or office, and design the experience accordingly.

When creating XR-based medical learning tools, developers should consider introducing randomized complications or problems that could occur during medical procedures or treatments as a way to educate clinicians on those potential complications as well as to test their situational awareness. For medical education, developers should decide if their

XR IN HEALTHCARE USE CASES

PHYSICAL AND OCCUPATIONAL THERAPY

XR devices and programs have already been approved by the FDA for use in physical and occupational therapy, for things like stroke recovery, spinal cord injury, motor rehabilitation, and treatment plans for those with Alzheimer's or Parkinson's.

Software developers interested in physical and occupational therapy should consider the following:

- Gesture and gaze tracking will likely need to include assessment tools so that clinicians can monitor patients' progress in increasing their mobility.
- For mobility impairments and motor control treatments, immersive experiences will need to be accurate in showing patients how to learn correct movements, and the use of haptic feedback or other tools to help patients make the correct gestures and movements if they are initially incorrect in replicating them.
- Data management and minimization should be the default, because the storage, utilization, and sharing of gesture and gaze tracking may implicate more privacy and HIPAA compliance issues.

content can be modified, adapted, and/or updated for future care and treatment, considering the evolution of hardware components and pace of progress in the clinical specialties addressed by their content.

Because medical science is constantly evolving, training and education material of all types, not just in XR, need to be able to adapt to changing understandings of diseases, treatments, and procedures.

Keep in mind that in certain situations, course materials may need to be made available outside of an immersive environment and/or without an XR headset. Because of that, learning programs should also be supported through a traditional browser or app on a desktop PC or mobile device.

Depending on the learning objective, immersive spaces may need to be kept simple, with few distractions from the task at hand. Or they may need to simulate the working environment a student or trainee might find themselves in, such as a hospital or clinic.

TESTING AND VALIDATION

Both educational institutions and job training programs will need to be able to assess whether a user of an XR educational program has learned new information, is able to perform clinical tasks correctly, and/or has participated fully in the immersive learning experience, among other things. Schools and employers may opt to create immersive assessment tools or tests that can be designed and implemented inside the virtual or augmented environment.

In addition to allowing instructors and trainers to create experiences for their students or trainees, software developers should consider providing them with role-based access to the XR system. The purpose would be to provide the ability for instructors to see how much time each student spent on each part of the experience, including whether a participant has missed or skipped a part of the experience.

Developers also should consider that post-training debriefing is standard practice in the medical field. Developers should create ways for educators to review the results of the training with learners and collect data during debriefing.

Assessment tools will vary based on the clinical specialty, student profile, and the learning environment (medical school v. job training, for example). A medical training simulation may require ways for the instructor to determine the skill in which the task was performed on a sliding scale of proficiency. Other learning objectives may require participants to make gradual progress over the course of several weeks or months, and therefore, should have tools for instructors to gauge a participant's progress and proficiency.

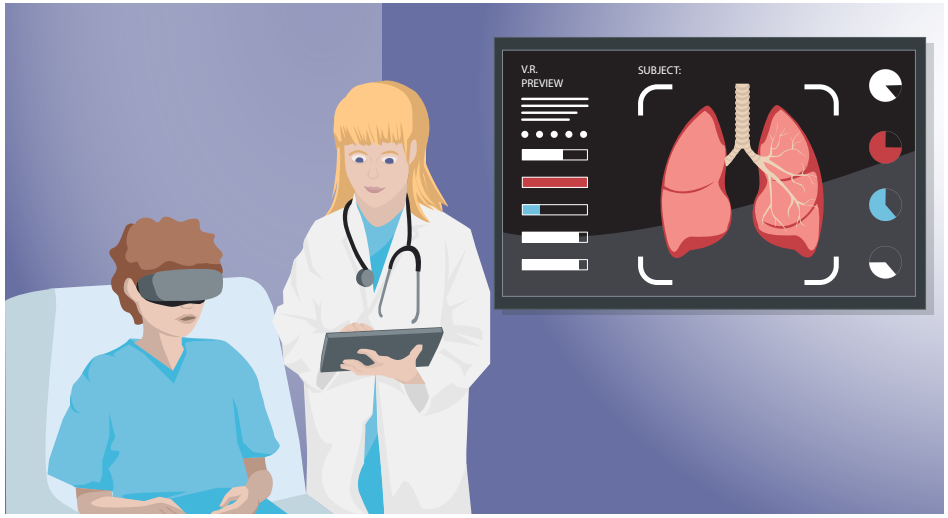
Medical simulations

Medical simulations using XR is a burgeoning area in both schools and for job training, and successful XR medical simulation development includes licensed clinicians who are subject matter or domain experts in the simulated procedures. This helps ensure that simulation content best addresses the needs of their audiences: clinicians, patients, educators, and students.

To improve the user experience and outcomes, developers of VR-based learning tools can implement touch simulation to complement and enhance audiovisual simulation. Haptic systems can output tactile feedback and force feedback designed to simulate the physical textures and resistance that a clinician may encounter when, for example, making an incision, inserting an IV, or performing any procedure that involves touching skin, bone, or tissue.

Clinicians often palpate (press on the surface of the body) to check patients for

XR IN HEALTHCARE USE CASES



medical symptoms. Developers creating VR learning tools that involve palpation should consider creating life-like haptic feedback that simulates the sensation of palpating a patient.

Developers should also consider how medical tools are handled or manipulated – for example, how a surgeon might hold a scalpel – and the weight of various instruments and clinical equipment.

Many training applications may want to include embedded assessment tools. Assessment tools differ depending on the student population and context for use.

JOB TRAINING

Job training tools in XR may run the gamut from training technicians on new medical equipment to introducing new or novel medical interventions for specific conditions to nurses or doctors to empathy and beside manner training. It may also be used as a refresher course for protocols and procedures established by specific medical institutions.

Importantly, job training materials will need to be vetted and developed in conjunction with a healthcare provider, such as an outpatient surgical center, a clinic, a hospital, or a doctor's office, and the routines, standard operating procedures, and preferences of each employer will likely differ. However, in general, job training programs should

A few helpful features for job training applications include:

- Allowing users to track their progress and log credit for the number of hours they have spent practicing or performing specific medical tasks/procedures and/or training for other skills.
- Including progress bars and/or other visual reminders of the routine care that every patient should receive in the facility, similar to a checklist that medical personnel might have to complete for patients.
- Making the training applications align with state and federal certifications and standards of best practice (including

PATIENT AND CAREGIVER EDUCATION

XR applications may be used to help explain complicated medical diagnoses and/or medical procedures to patients, their caregivers, and/or their loved ones. It also can reduce questions and misunderstandings between doctors and patients (who often have limited time with each other).

When developing for patient and caregiver education, developers should consider the following:

- Education should be true to the patient's circumstances, injury, or illness. For example, it should allow doctors to include X-rays and other imaging specific to the patient that may be helpful in explaining the medical issue
- When applicable, shows what a healthy or recovered scenario looks like
- User interface should be simple and intuitive to use for patient/caregiver/doctor
- Starting up the XR hardware and application should be quick and easy
- Ill or injured patients may have limited mobility, so six degrees of freedom may not be appropriate or required.

XR IN HEALTHCARE USE CASES

Healthcare Simulation Standards of Best Practice).

- Including measures of how efficacy and outcomes so data can be shared with partners.
- Disaster training and infection control scenarios.
- Give users various settings and scenarios, such as ER patients, patients who are unconscious, patients who are attached to medical equipment such as IVs or ECGs, etc.
- Safety protocols and regulations for the patient and provider.
- Institution-specific patient onboarding processes.

For empathy and bedside manner training, developers may want to include:

- Randomized patient responses to similar illnesses or questions that doctors/nurses need to ask during patient interviews.
- Virtual patients (and their loved ones) with varying temperaments and behaviors to teach "soft skills," such as management of conflict and dealing with difficult patients, parents, partners, etc.
- Mental health training as well as physical disease diagnosis.

SOFTWARE FOR USE DURING SURGERY

Software for use during surgery is highly complex and specialized, and companies developing XR programs for use during surgery will likely need to seek FDA approval.

When considering surgical applications of XR, developers may want to consider:

- When using AR during surgery, virtual screens should be able to be moved to a comfortable viewing angle for the doctor or clinician.
- VR experiences should attempt to replicate as close as possible real-life surgical lighting.
- Inclusion of the other attendants that will be participating in the surgery and where they will be located.
- Whether the XR system is intended for use by multiple members of the surgical team or just the surgeon(s).
- How AR overlays appear so that they do not distract focus away from the patient's real-life condition.
- Interoperability with other hardware and software used during surgeries. Surgical equipment is often proprietary and could have interoperability conflicts with XR programs.
- Resolution and compatibility with filming equipment. Surgeons require recording equipment to fit into their workflows (loops, hi-res recording, controllers, 360 recordings blended with 2D videos (close-ups).

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The XR Association promotes the dynamic global growth of the XR Industry, which includes virtual reality, augmented reality, mixed-reality, and future immersive technologies. XRA is leading the way for the responsible development and adoption of XR by convening stakeholders, developing best practices and research, and advocating on behalf of our member and the greater XR industry.

The XR Association represents the broad ecosystem of the XR industry including headset manufacturers, technology platforms, component and peripheral companies, internet infrastructure companies, enterprise solution providers, and corporate end-users. The founders of XRA are Google, HTC Vive, Microsoft, Meta, and Sony Interactive Entertainment.

XR ASSOCIATION

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